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Mean Excitation Energy for the Stopping Power of Light Elements*

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The primary process in radiation damage, Coulomb excitation of electrons, was first treated by Bethe, who related the incident particle's energy loss to the irradiated material's optical properties. His results are summarized by the mean excitation energy, *I*,

$$\ln I = \int f(\omega) \ln \hbar\omega \, d\omega \Big/ \int f(\omega) \, d\omega \, .$$

The integrations extend over all frequencies, ω, and $f(\omega) \propto -\omega \operatorname{Im} \varepsilon[(\omega)]^{-1}$ is the oscillator strength with $\varepsilon(\omega)$ the dielectric function. Until recently, experimental values for $\varepsilon(\omega)$ were not available over a sufficient range to evaluate the integrals for any material, and *I* values were derived indirectly from stopping-power measurements, an approach requiring corrections, often approximate, for a variety of atomic effects. However, with the advent of synchrotron light sources, sufficient absorption data have become available, particularly at vuv and soft-x-ray energies to give the dielectric function for several elements. This has allowed us to carry out Bethe's original program of direct evaluation of *I* from ε. The dielectric response was found using a self-consistent Kramers-Kronig analysis of absorption, refraction, reflection, and EELS measurements on carbon (as graphite), metallic aluminum, and crystalline silicon. The *I* value was calculated cumulatively to demonstrate the contribution of each atomic shell. We find:

- K and L shell are the dominant contributors to *I* in light elements;
- Valence electrons make little contribution, hence the weak effects of chemical bonding;
- Si and Al have nearly equal *I* values, despite silicon's extra valence electron. The additional electron simply makes negligible contribution to the average. This conflicts with Bloch's relation, $I \propto Z$, which is based on the Thomas-Fermi statistical atom.
- Dielectric-function *I* values for C and Al are in good agreement with values from stopping-power measurements. However, the dielectric *I* value for Si is 164 ±2 eV, bringing the ICRU stopping-power-based recommendation of 173 eV into question.

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